SEMIANNUAL STATUS REPORT

NASA Research Grant NAG-1-678

SPACE ENVIRONMENTAL EFFECTS ON POLYMERIC MATERIALS

March 1, 1986 to January 1, 1987

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Space structures in geosynchronous orbit will be subjected to radiation doses of about 10^{10} rads over a 30 year lifetime. In addition, daily thermal cycling will occur. These structures will likely be constructed of polymer matrix composite materials because of their light weight, high strength, and low-thermal expansion. Radiation is known to initiate chain scission and crosslinking in polymeric materials, both of which affect their structural properties. Thus, a study of the effect of radiation on polymers is important in estimating the impact of the space environment on composite structures.

In this study, two commercially available polymer films were used; a polyetherimide, and a polysulfone. The polyetherimide was produced by the General Electric Company with the trade name Ultem. The polysulfone was produced by the Union Carbide Corporation as P1700. The two polymers were chosen for study because they had been well characterized, they were commercially available in good quality films, and they are both linear systems. Both films were irradiated in vacuum with 85 KeV electrons. Properties of the films before and after irradiation were monitored by tensile elongation measurements, ultraviolet/visible spectroscopy, glass transition temperature measurements, gel permeation chromatography, and infrared spectroscopy.

The polyetherimide, Ultem, becomes colored when it is irradiated, a characteristic common to many polymer films. However, when Ultem is exposed to air after irradiation, the color fades. In order to quantify this color change, ultraviolet/visible (UV/VIS) spectra of irradiated Ultem films were recorded at various times after the irradiation beginning at 5 minutes and extending to at least 4 hours, as shown in figure 1. The spectra were recorded on a Perkin-Elmer Model 330 spectrophotometer. Irradiations were performed with total doses of 100, 320, 640, 2000, and 4000 Mrads. Dose rates ranged from 4.2 to 170 Mrads/hr. The percent transmittance was determined at a specific wavelength (490 nm) for each spectrum so that a plot of %T vs time after exposure could be made as shown in figure 2. It can be

seen that the %T at 490 nm increased with time after exposure up to a maximum value which was always less than that of the unirradiated film. The %T at each time was then subtracted from this maximum or equilibrium value. The log of the remainder is plotted as a function of time after exposure in figure 3. This plot shows the decay of the color and thus the decay of the specie causing the color. Figure 3 shows two distinct groups of points, those from films irradiated at high doses (2000 and 4000 Mrads) and those irradiated at lower doses (320 and 640 Mrads). The color of the films irradiated at high doses decayed with a 90 minute half-life while that of the films irradiated at the lower doses decayed with a 40 minute half-life. It has been shown by ESR spectroscopy that for a 1600 Mrad irradiation of Ultem, the radicals decay with a 90 minute half-life.[1] Thus, there is good evidence that the decay of the color centers is due to radical decay. It has also been shown that the critical gel dose for Ultem is about 1100 Mrads.[2] Therefore, it appears that above the critical gel dose, the radicals decay more slowly due to a decrease in mobility or to a change in decay mechanism. The UV/VIS data as a function of total dose is summarized in figure 4.

Because the Ultem contains radicals which decay with a measurable half-life when exposed to air, tensile elongation studies were run as a function of time after irradiation to see if the radical decay affected the mechanical properties of the polymer. Total doses and dose rates were the same as those used for the UV/VIS studies. In these studies, the irradiated films were removed from the vacuum chamber and immediately immersed in liquid nitrogen. Films were then removed and exposed to air for a period of time before the tensile elongation test was made. Time periods of 0, 15, 30, 60, and 120 minutes were used. Within experimental limits, no effect of time in air on the tensile elongation was noted at any total dose studied. In addition, two samples were irradiated at 320 Mrads and allowed to remain in vacuum for 4 days before making the tensile elongation measurements. Again, no effect with time was noted. The data are summarized in figures 5, 6, and 7. The infrared spectrum was also measured as a function of exposure time in air, and again, no effect was noted.

The Ultem irradiations show that for optical properties, post-irradiation effects are important, particularly for the first several hours. Post-irradiation handling appears to have no effect on the tensile elongation and the infrared spectrum.

To compare the behavior of Ultem with that of another polymer, polysulfone (P1700) was irradiated and treated in an identical manner as the Ultem. No effect was found in either the tensile elongation or the UV/VIS spectrum as a function of exposure time in air. Figure 8 shows the UV/VIS spectrum for polysulfone as a function of exposure time in air. This can be compared with figure 1.

Since polysulfone showed no post-irradiation effects, it appeared to be an ideal polymer to use for a study of dose rate and temperature effects on the tensile elongation. In the dose rate study, the total dose was held constant at 350 Mrads and the temperature was constant at 25°C while the dose rate was varied between 1.8 and 260 Mrads/hr. The results as shown in figure 9 indicate that over the range of dose rates studied, there is no effect on the tensile elongation.

For the temperature study, the total dose and dose rate were constant at 350 Mrads and 87.5 Mrads/hr respectively, while the temperature was varied between 25 and 175°C. The results are shown in figure 10. Above 110°C, the tensile elongation drops to zero. This probably occurs because the critical gel dose decreases at the higher temperatures so that by 125°C it is below 350 Mrads. Brown and O'Donnell have shown that for gamma irradiation of polysulfone (P1700), the critical gel dose decreased from 400 Mrads at 35°C to 100 Mrads at 125°C.[3] This is qualitatively in line with our data. There appears to be a slight increase in tensile elongation as the temperature increases from 25° to 110°C. It has been shown for this polysulfone that the ratio of chain scission to crosslinking, G(S)/G(X), increases with increasing temperature.[3] This would cause an increase in tensile elongation with increasing temperature up to the point where the critical gel dose is exceeded.

The data indicate that for polysulfone (P1700), temperature affects the tensile elongation and thus the structural properties, while dose rate over the range studied has no effect.

References

1. E.R. Long and S.A.T. Long, NASA TP-2429, May 1985.
2. R. Basheer and M. Dole, Radiat. Phys. Chem., 25, 389 (1985).
3. J.R. Brown and J.H. O'Donnell, J. Appl. Polym. Sci., 23, 2763 (1979).

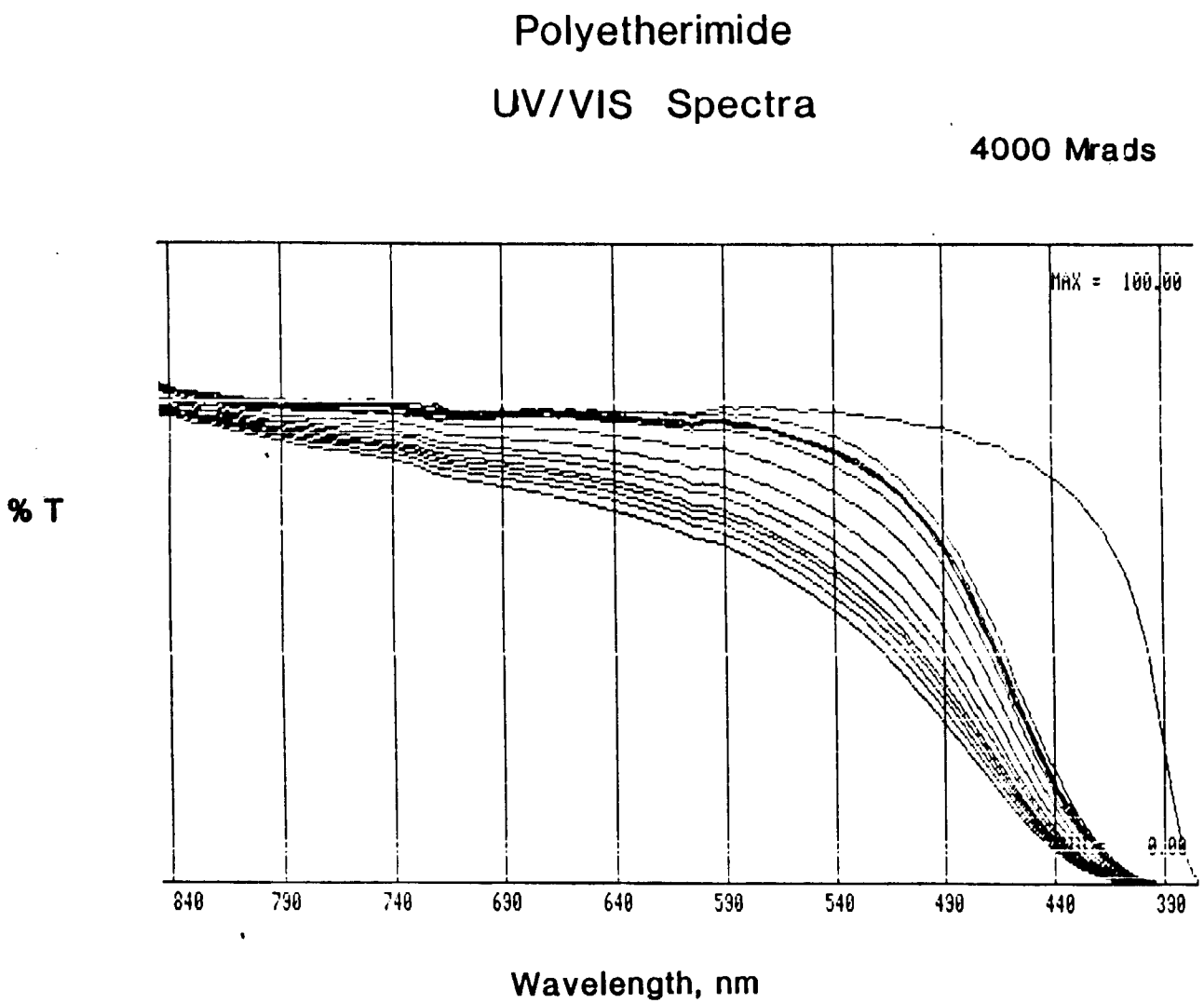

Figure 1. UV/VIS spectra of Ultem taken 5 minutes to 4 hours after irradiation.

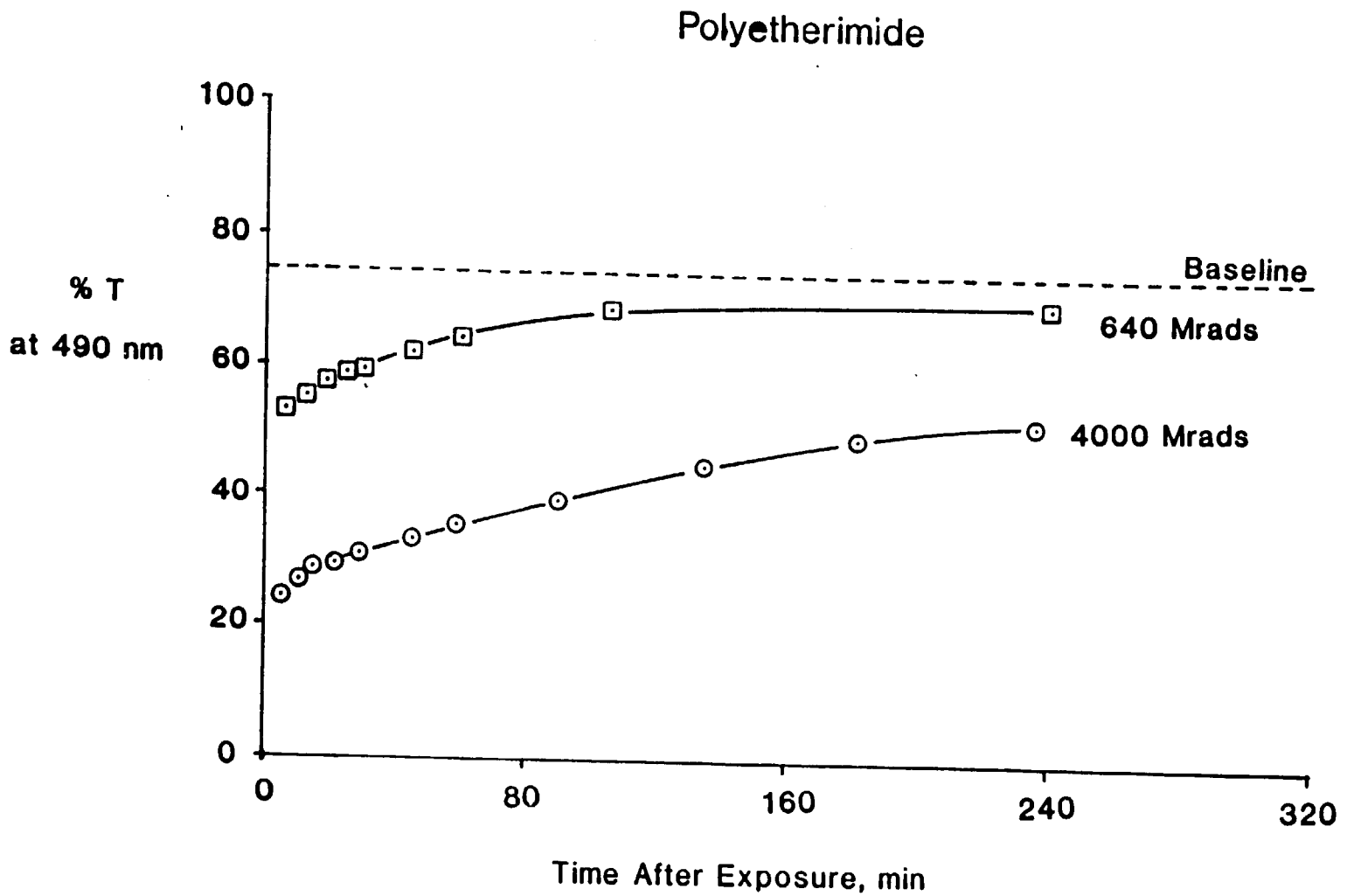

Figure 2. Percent transmittance at 490 nm of irradiated Ultem as a function of time after irradiation.

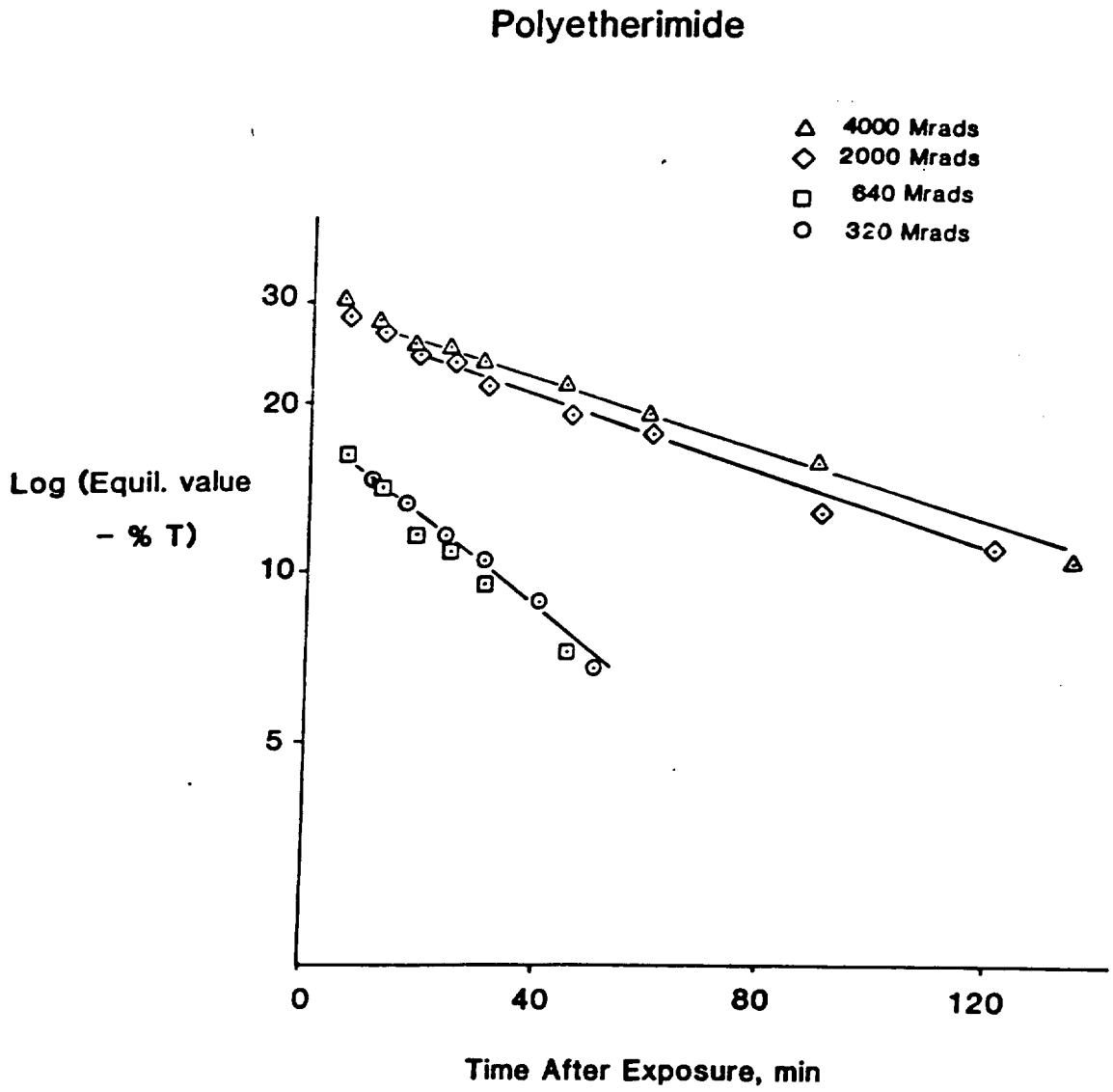

Figure 3. The decay of the color centers of irradiated Ultem.

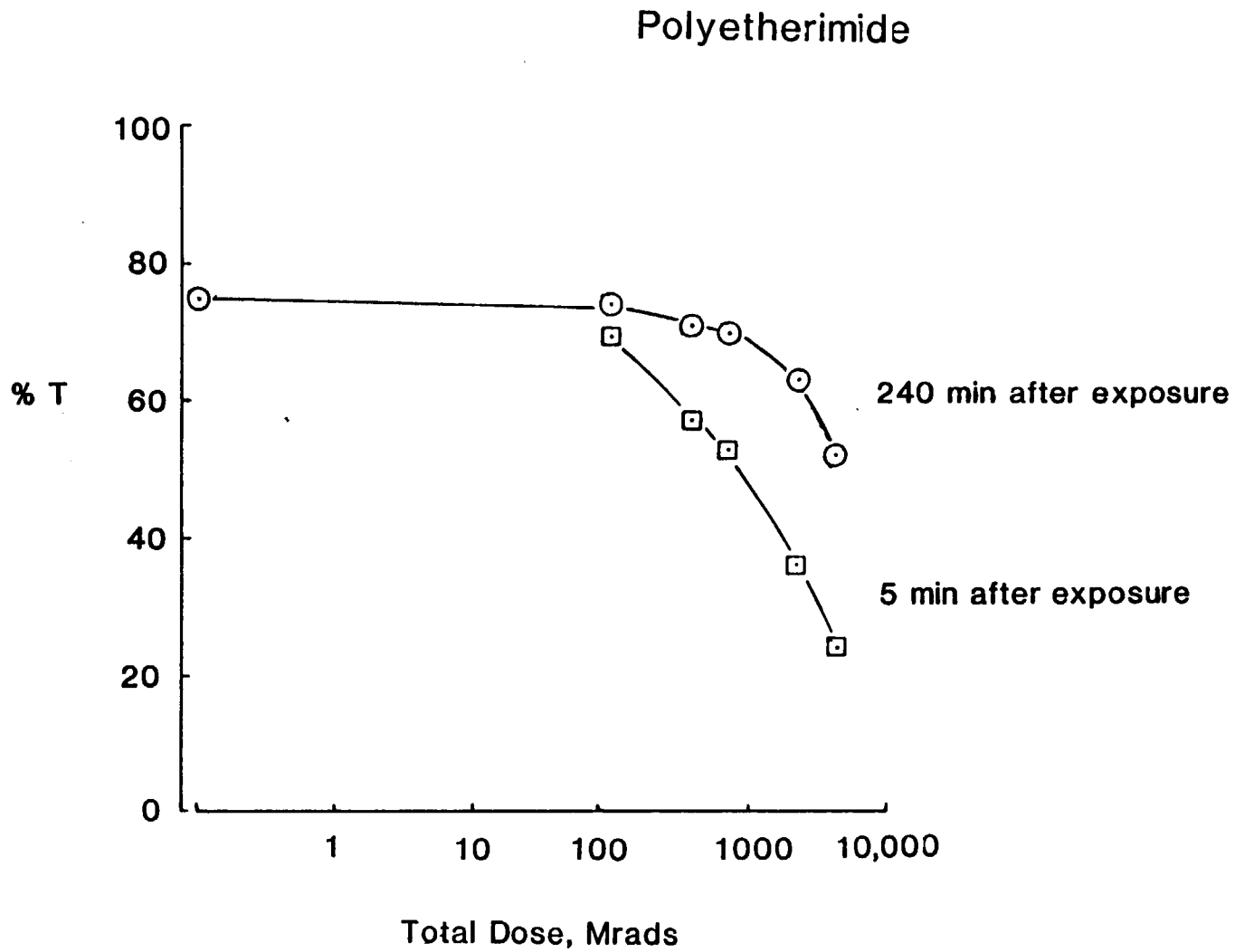

Figure 4. Percent transmittance of irradiated Ultem as a function of total dose.

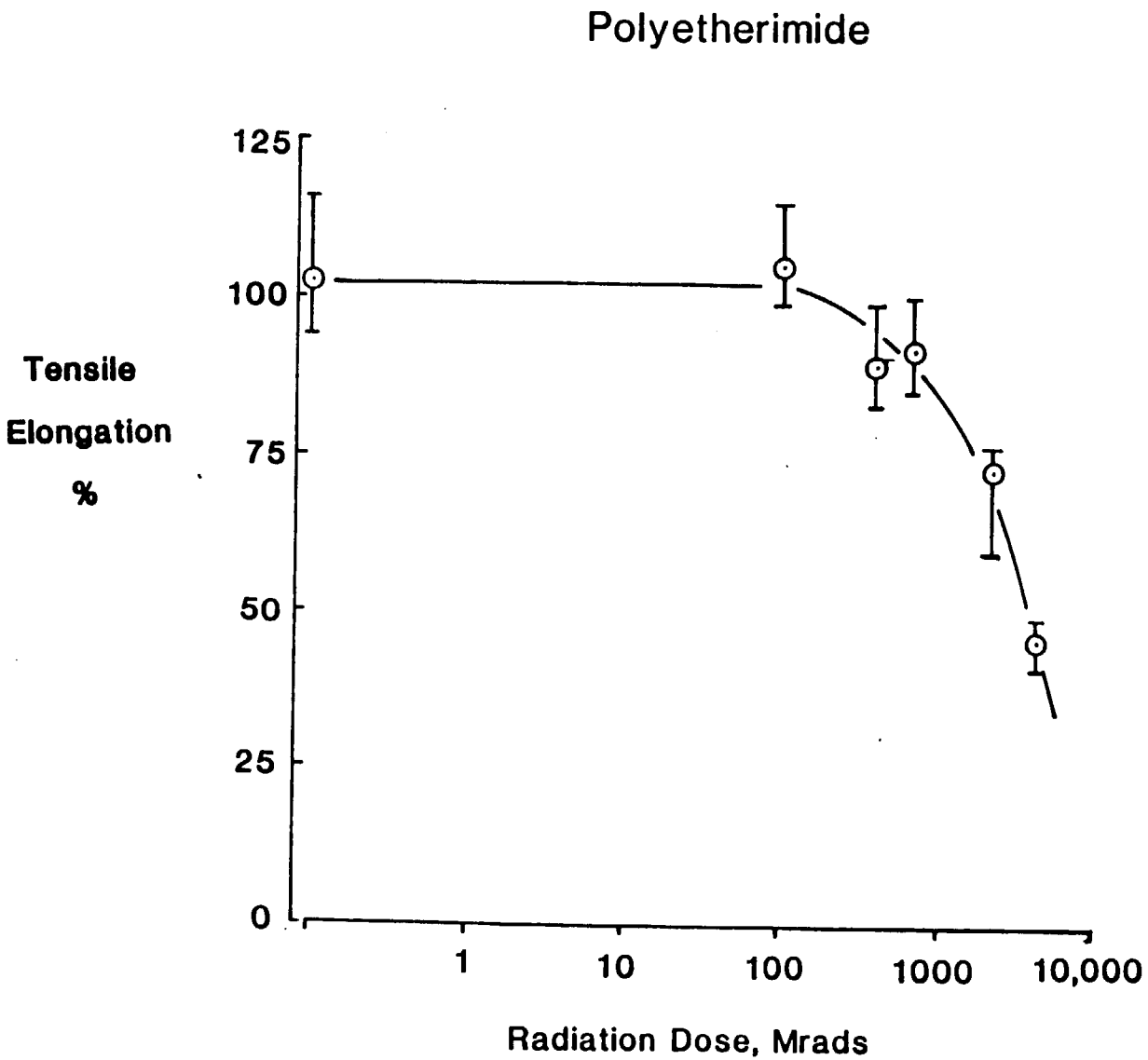

Figure 5. Tensile elongation of irradiated Ultem as a function of total dose.

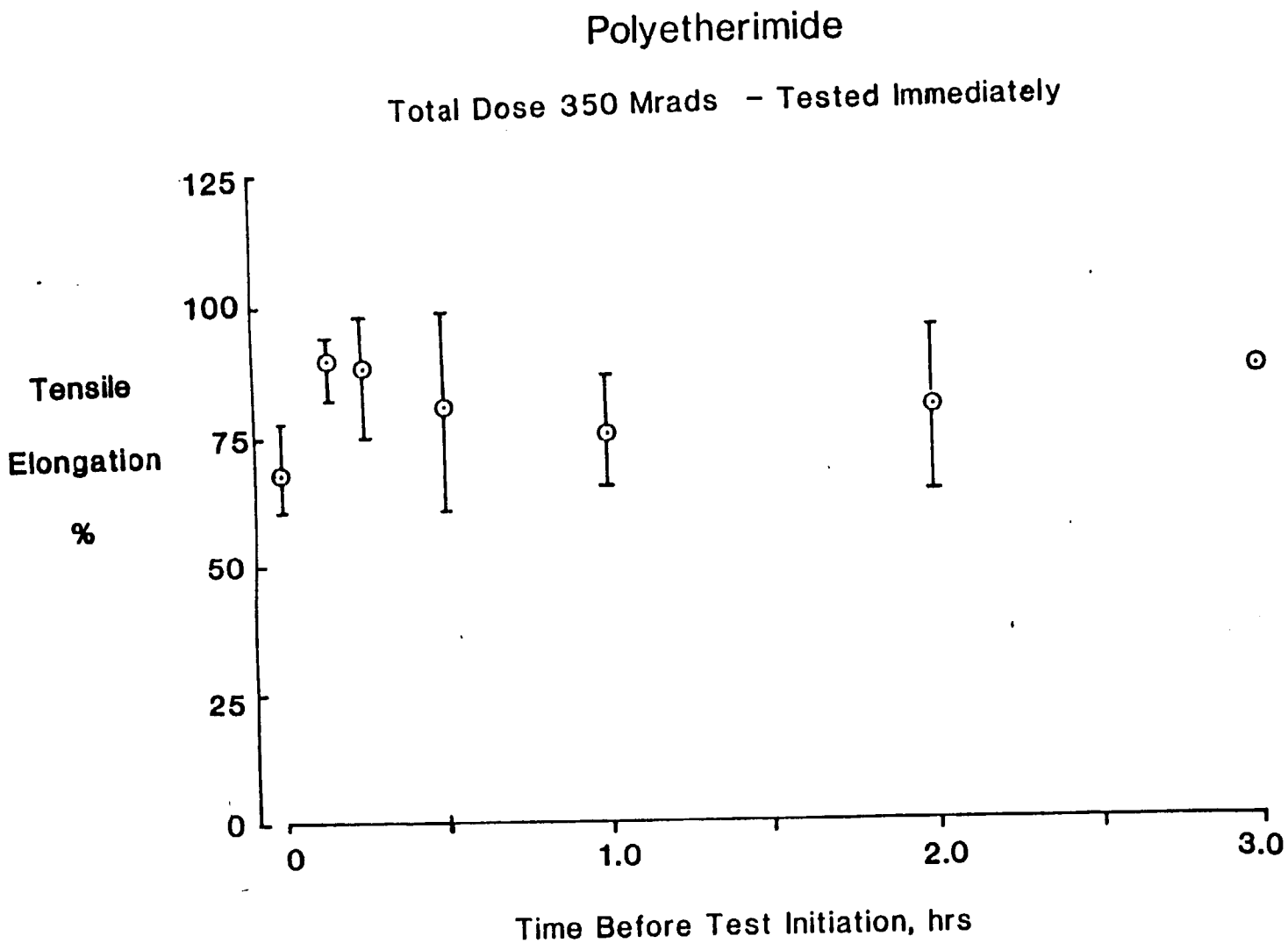

Figure 6. Tensile elongation of irradiated Ultem as a function of exposure time in air.

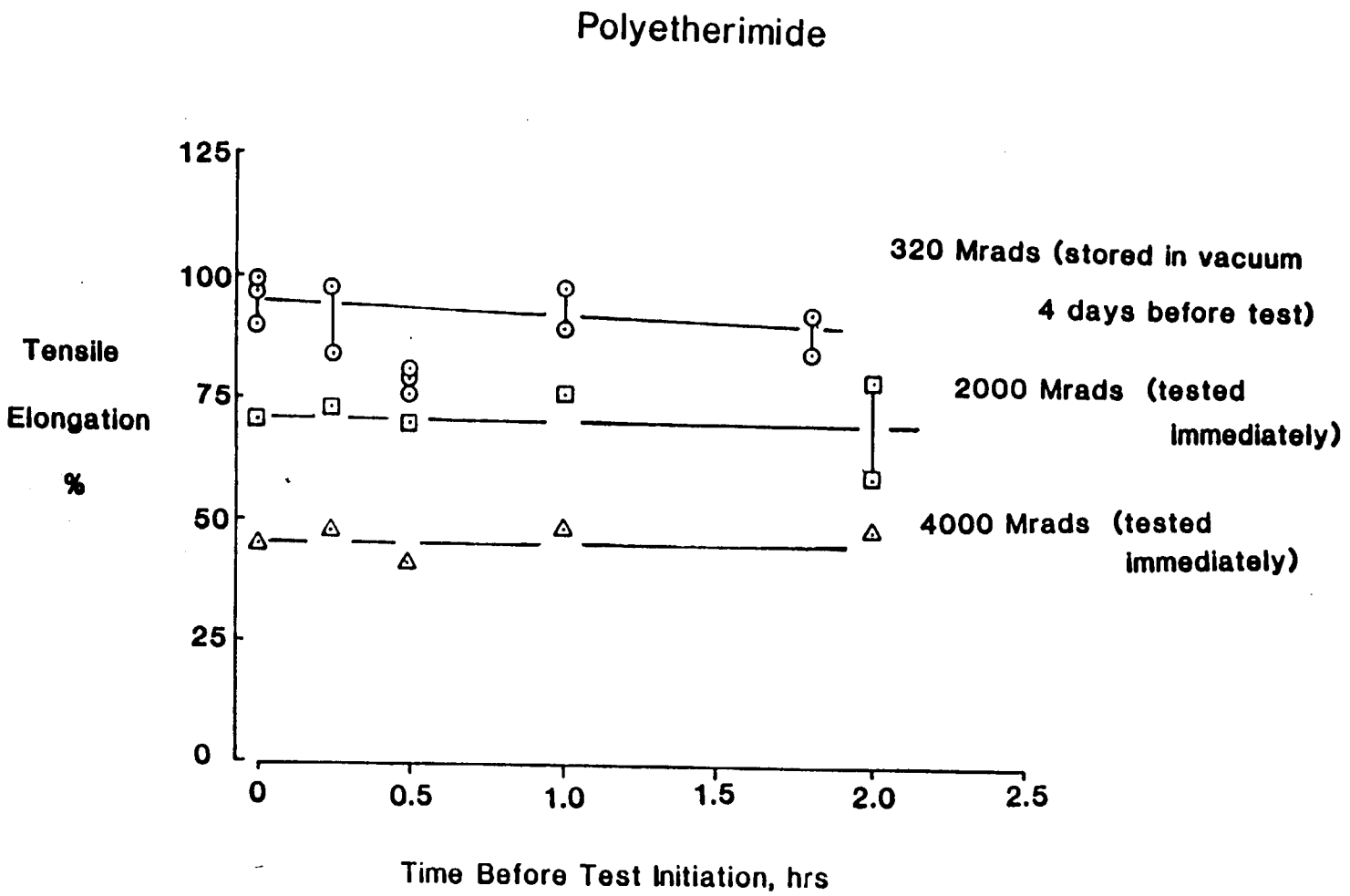

Figure 7. Tensile elongation of Ultem irradiated to various doses as a function of exposure time in air.

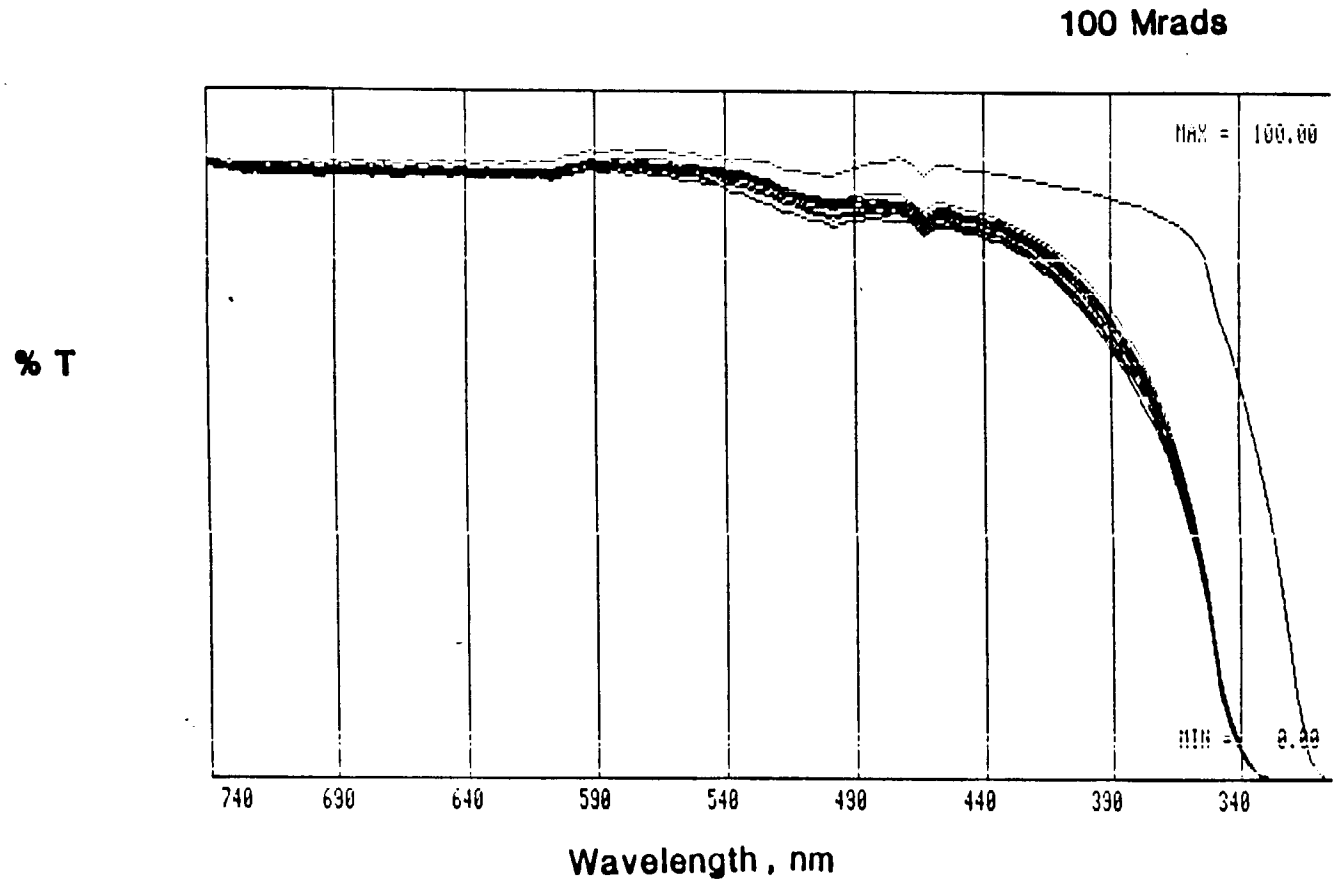

Figure 8. UV/VIS spectra of polysulfone taken 5 minutes to 4 hours after irradiation.

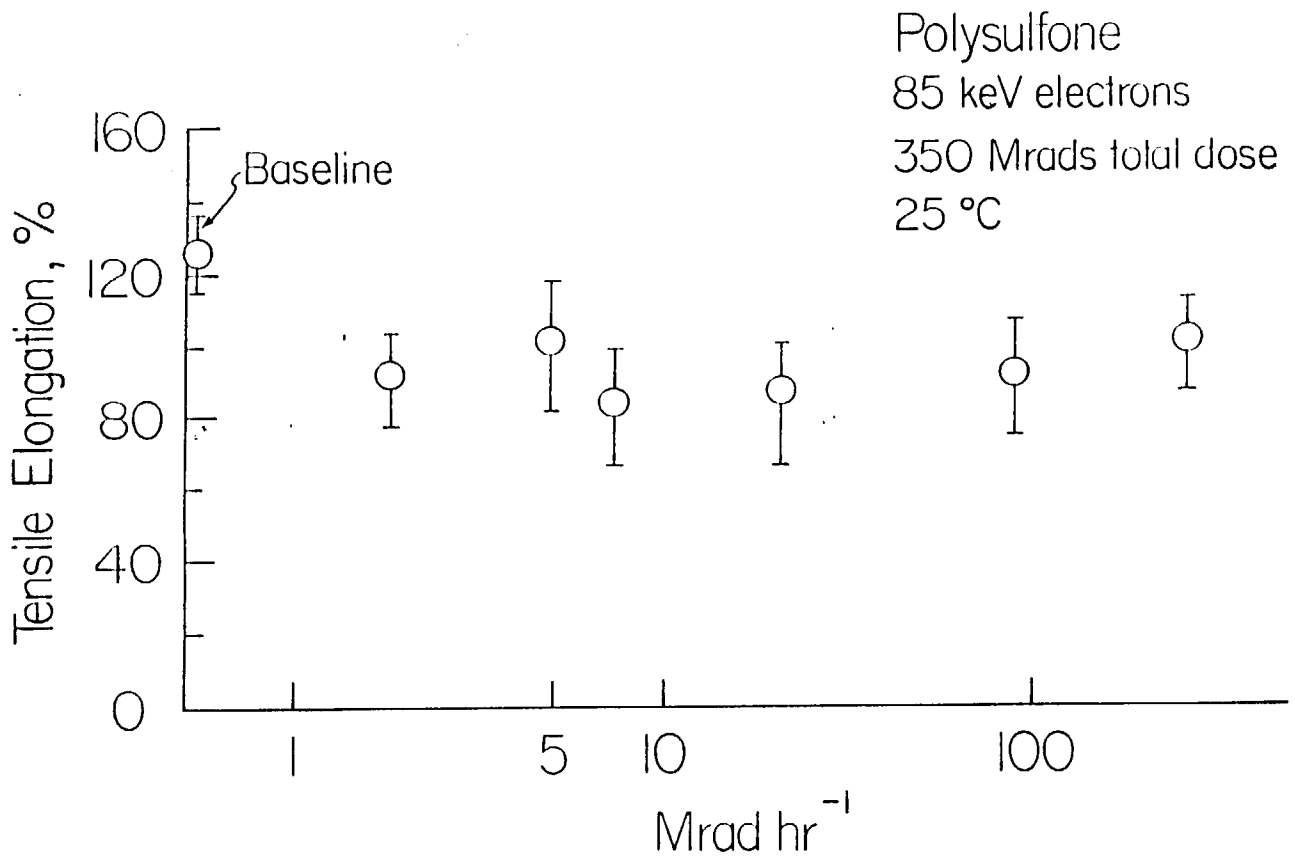

Figure 9. Tensile elongation of polysulfone as a function of dose rate.

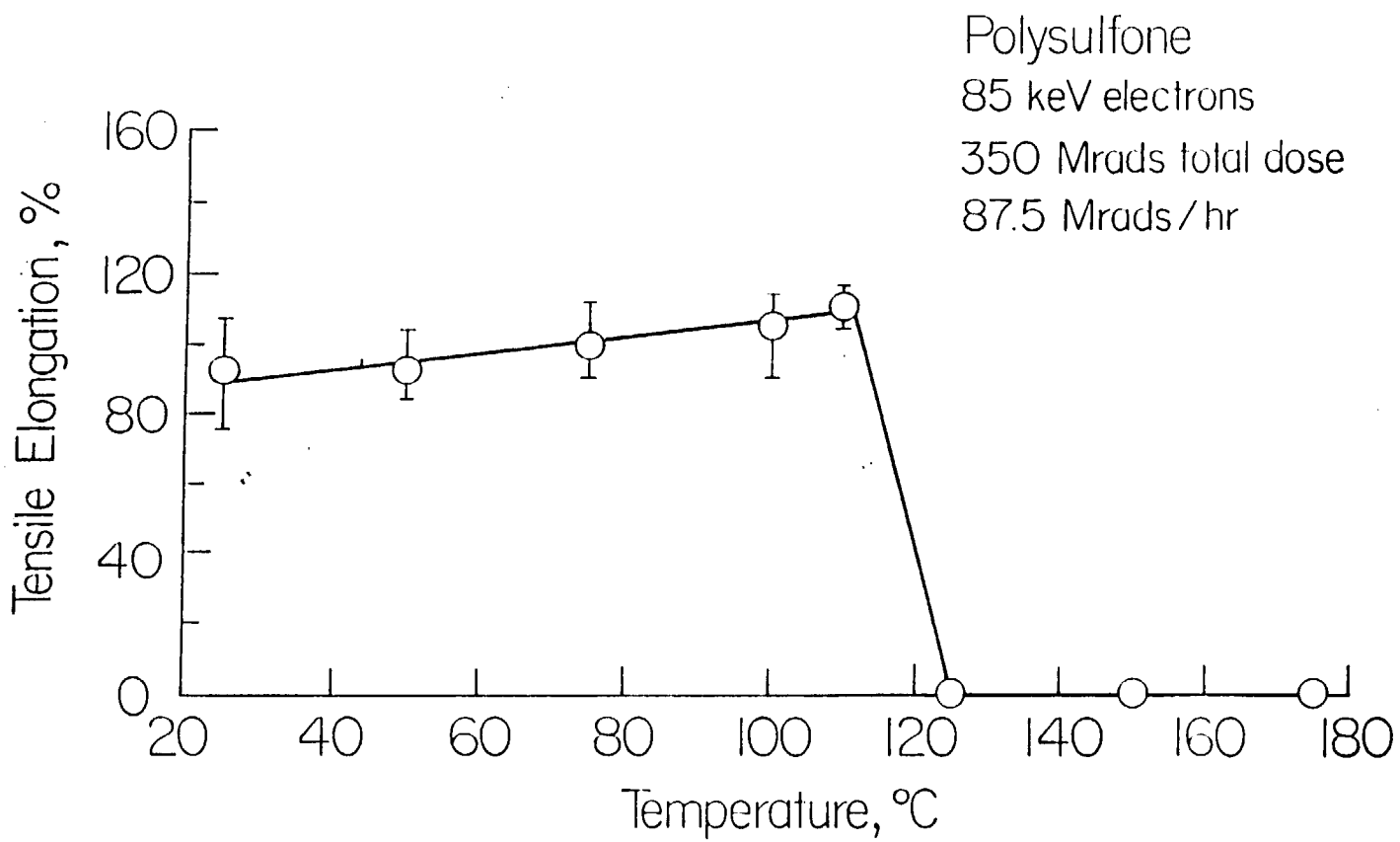

Figure 10. Tensile elongation of polysulfone as a function of temperature.